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Carbon pricing of basic materials: Incentives and risks for the value chain and consumers

Jan Stede*, Stefan Pauliuk, Gilang Hardadi**, Karsten Neuhoff***

For the European Union to realise its ambition of carbon neutrality, emissions from basic material production need to be reduced through low-carbon production processes, material efficiency and substitution, as well as enhanced recycling. Different reform options for the EU ETS are discussed that ensure a consistent carbon price incentive for all these mitigation options, while avoiding the risk of carbon leakage. This paper offers a first quantification of potential carbon leakage risks, distributional implications and additional revenues associated with different mechanisms: an import-only border carbon adjustment (BCA), a symmetric BCA, and an excise for embodied carbon emissions at a fixed benchmark level in combination with continued free allocation. We estimate the product-level carbon intensities for about 4,400 commodity groups, including basic materials, material products, and manufactured goods and compute implied price changes and cost increases relative to gross value added to assess the scale of carbon leakage risks.

Keywords: emissions trading, border carbon adjustment (BCA), excise duty, carbon intensity, carbon leakage, distributional effects, fiscal revenues
JEL codes: F18 Trade and Environment, C67 Input–Output Models

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1 Introduction

The European Union (EU) envisages a shift to climate neutrality by mid-century. This will require the decarbonisation of production of basic materials such as cement, steel, and aluminium, which accounts for around 25% of global CO_2 emissions (IEA, 2017). Decarbonisation will require not only a shift to climate neutral production processes for primary materials (Davis et al., 2018) but also a more efficient material use, substitution with alternative lower carbon materials, and enhanced recycling.[1]

To realize this portfolio of mitigation options, a package of policy instruments is being discussed (Climate Strategies, 2019), and effective carbon pricing is considered an important element to cover incremental costs of climate neutral production technologies as well as to provide financial incentives for the various demand side mitigation opportunities (Goulder and Parry, 2008; Bertram et al., 2015; Stiglitz et al., 2017; Climate Strategies, 2019).

For carbon pricing to support the transition to climate neutrality of basic materials, the carbon pricing design needs to meet two criteria: First, carbon costs need to be reflected along the value chain to incentivise the various mitigation options and to ensure incremental costs of climate neutral options can be recovered by producers. Second, concerns about carbon leakage need to be addressed. Carbon pricing could result in carbon leakage if higher domestic carbon costs lead to a replacement of domestic production and emissions with foreign production and emissions. Concerns about carbon leakage can erode the economic and environmental case, as well as political support for carbon price levels necessary to effectively contribute to the transition to climate neutrality.

Historically, carbon leakage risks have been successfully addressed with free allocation of allowances to producers of basic materials (Martin et al., 2014; Sato et al., 2015; Branger et al., 2016; Naegele and Zaklan, 2019). However, as a result of free allocation and international tradability of materials, only a fraction of the carbon costs is passed on along the value chain to basic material products, components and final products (Branger et al., 2015; de Bruyn et al., 2015; Martin et al., 2016; Neuhoff and Ritz, 2019). Therefore, carbon pricing fails to provide effective incentives for a transition to climate neutrality.

A variety of options for reforming the European Emission Trading System (EU ETS) are being discussed to resolve the trade-off between consistent carbon pricing (i.e. reflecting embodied emissions of a material or product in its price) and the environmental, economic and political objective of avoiding carbon leakage. These options include border carbon adjustments (BCAs) as an alternative to free allocation, or combining continued free allocation with consumption-based charges (for an overview of the literature and different policies see Cendra, 2006; Branger and Quirion, 2014; Böhringer et al., 2017; Cosbey et al., 2019; Felbermayr and Peterson, 2020).

Existing literature has focused on the risks for basic material producers from carbon costs under the EU ETS (see the meta-analysis by Branger and Quirion, 2014). This focus was sufficient, because the traditional mechanism to address carbon leakage risks was to reduce these carbon costs by

[1] See Carruth et al. (2011) and Horton and Allwood (2017) for a manufacturing perspective, IEA (2018) for a sector perspective and Material Economics (2019) for the overall scale of mitigation potential from an efficient material use.

granting free EU ETS allowances to basic material producers. As a result, also carbon costs in the value chain and in export markets were limited. In this work, we explore the consequences of carbon pricing of basic materials that propagates along the value chain for key indicators such as carbon leakage risks, distributional implications on household consumption, and public revenue from carbon pricing mechanisms. The following summary introduces the different sections of this report and synthesizes their main findings.

Section 2 provides the methodological foundations by calculating material-specific carbon benchmark reference values that are subsequently applied to calculate the embodied emissions related to the key basic materials that could be covered by a BCA or excise, namely cement, steel, aluminium, plastics, pulp and paper. This allows us to calculate product-level price increases due to consistent carbon pricing for about 4,400 commodity groups.

Section 3 assesses potential carbon leakage risks along the value chain, i.e., the risk of relocating production and therefore emissions to regions outside of the EU. With a shift to full auctioning in combination with border-related measures, carbon costs will be passed to material prices. Hence potential carbon leakage risks for manufacturing industries along the supply chain in domestic and in export markets need to be considered.

Domestic carbon pricing without free allocation combined with a BCA could cause carbon leakage through two channels. First, in BCA options covering only imports, the costs of full auctioning increases material prices and hence production costs of domestic industry. This could result in a substitution of exports with an increase of production and associated emissions by industry in other regions. Second, for all BCA options it is typically assumed that coverage of imports is restricted to basic materials and products only comprising one basic material (basic material products). Due to full auctioning it is likely that carbon costs will be reflected in the prices of basic materials and basic material products. For the next step of the value chain, domestic producers will face higher costs for inputs, but will only partially be able to reflect these costs in the prices of their products, as competing imports would not be covered by the BCA. This could again result in a replacement of domestic production and emissions by imports.

To identify which industrial activities may be exposed to a risk of carbon leakage through these two channels, we compute the ratio of carbon costs relative to gross value added (GVA) for 4,400 product categories along the value chain. We thus apply the indicator used to assess carbon leakage risk under the EU ETS until 2020 for primary material producers (Directive 2003/87/EC, see Sato et al., 2015) also to basic material products, components and final products. The carbon cost increase relative to value added for basic materials is on average 23%, and remains high for basic material products with an average of 9%. While the average cost increase relative to value added declines to 1.5% and 1.3% for components and final products, a variety of products and components exhibit cost increases exceeding 5% (Table 1).

Table 1: Carbon cost increase (in %) relative to GVA in different product categories

	Mean	Median	Max	Min	Standard deviation
1: Basic materials	23.0	11.2	155.8	0	33.9
2: Basic material product	8.8	2.4	108.9	0	15.1
3: Components	1.5	0.7	32.5	0	3.7
4: Final products	1.3	0.2	45.0	0	3.6

The statistics (in percent) are calculated for a carbon price of 30 EUR/tonne under the assumption of full carbon cost pass-through (i.e. without free allocation of allowances). Product categories are defined in section 2.3.2.

In line with the threshold defined in the EU ETS Directive, we consider product categories potentially at risk of carbon leakage that meet two criteria.[2] First, carbon costs relative to GVA exceed five percent. Second, the product category exhibits a trade intensity of at least 10 percent.[3]

For an import only BCA in combination with full auctioning, we find that almost 190 billion euros or 10 percent of EU exports meet the criteria for potential carbon leakage risk at a carbon price of 30 EUR/t (Figure 1). This share would increase to almost a quarter of all exports (450 billion euros) for a carbon price of 75 EUR/t.

[2] The 5% threshold for the assessment of carbon leakage risks in Art 10a(15) of Directive 2003/87/EC has been replaced for the period post-2020 by a new indicator based on the product of trade intensity and emissions intensity (emissions divided by gross value added).

[3] Trade intensity is defined as the sum of the value of imports and exports, divided by the EU market size (domestic sales plus imports).

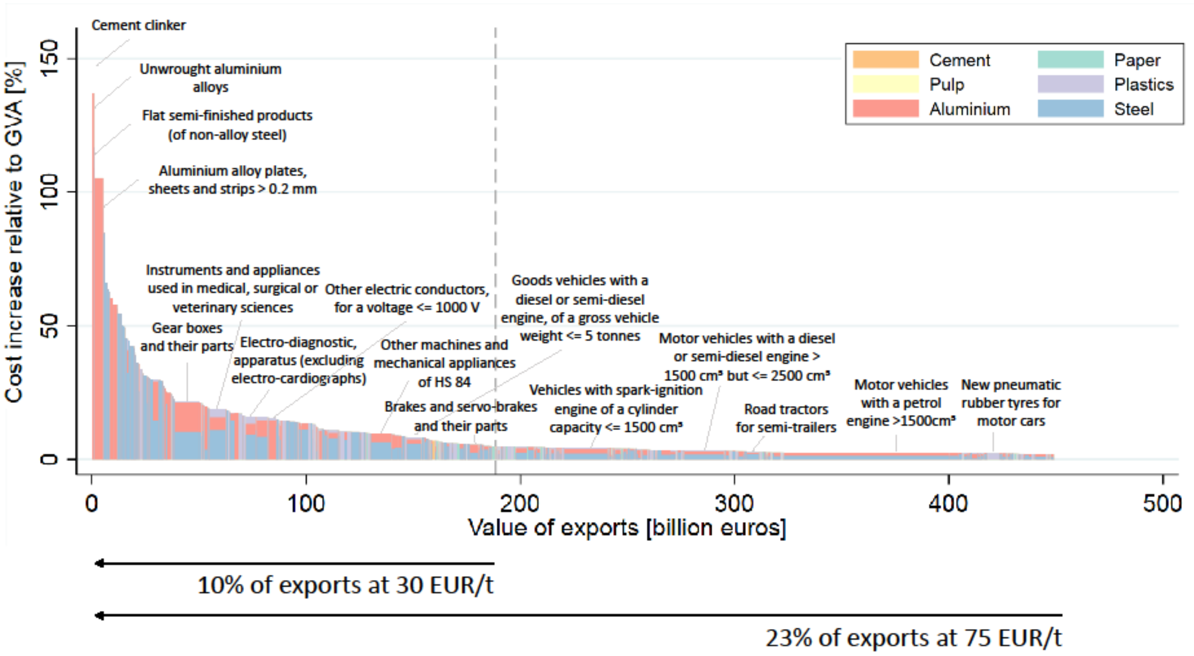

Figure 1: Products potentially at risk of carbon leakage in export markets under a BCA without reimbursement for exports

Based on EU-27 PRODCOM manufacturing data (NACE codes 10-33) from 2019. Cost increases relative to GVA are based on a carbon cost of 30 EUR/t, under the assumption of full carbon cost pass-through.

We also assess the implications of border carbon adjustment mechanisms only applied to basic materials or basic materials and basic material products and find significant carbon leakage risks for components and final products. For a BCA that does not extend to components and final products, we find that 242 billion euros of domestic sales of components and final products (equalling five percent of overall sales of EU manufacturing) meet the criteria for risk of carbon leakage at a carbon price of 30 EUR/t (Figure 2). The corresponding sales volume increases to 760 billion euros (or 15 percent of manufacturing) for a carbon price of 75 EUR/t.

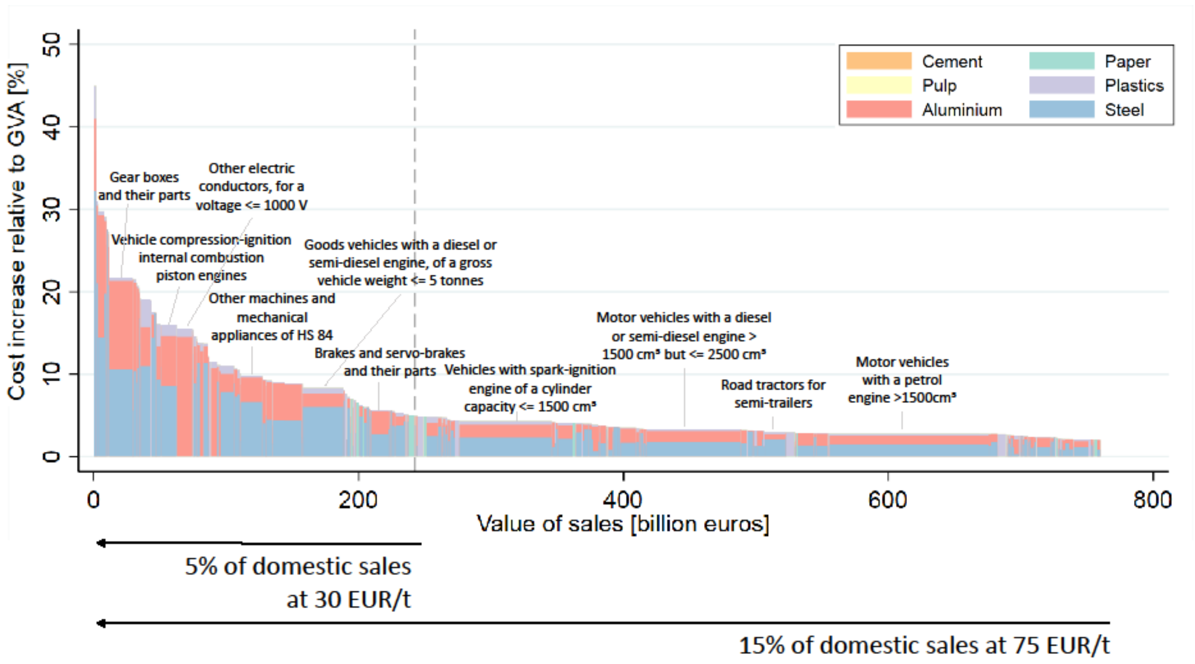

Figure 2: Components and final products potentially at risk of carbon leakage under a BCA that covers only basic materials and basic material products

Based onEU-27 PRODCOM manufacturing data (NACE codes 10-33) from 2019. Cost increases relative to GVA are based on a carbon cost of 30 EUR/t, under the assumption of full carbon cost pass-through. Product categories are defined in section 2.3.2.

Section 4 shows that the distributional consequences of consistent carbon pricing for basic material production are limited and progressive. We find that the effect of a carbon price of 30 EUR/t on consumer expenditure is small and slightly progressive (Figure 3): German consumers are estimated to spend below 0.2% of total disposable income, with the share slightly increasing by income decile. Even this small effect is likely an over-estimation of the actual effect on household expenditure of the implementation of a BCA or an excise, since there is likely to be some existing carbon cost pass-through already today. Furthermore, in the mid-term, demand response (e.g. due to increased material efficiency) may reduce the price effects.

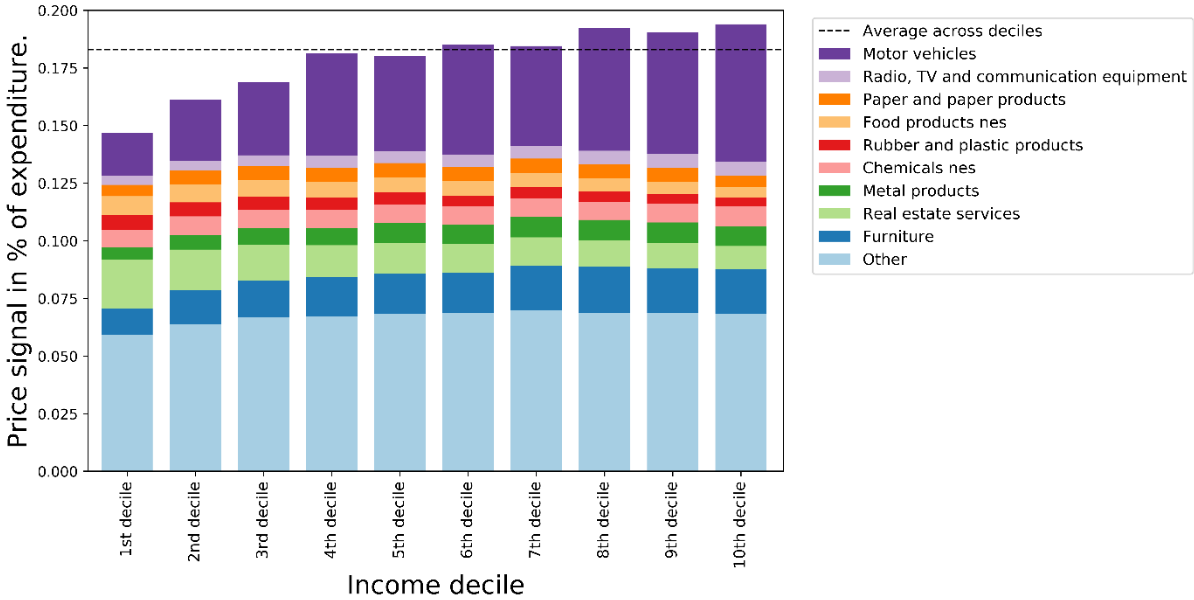

Figure 3: Carbon cost related price increase for German households by income decile in percent of the total expenditure

Price increase assuming carbon costs of 30 EUR/t are reflected in basic material prices and all products comprising basic materials. Total expenditures are divided into 163 subgroups, of which the nine with the largest price signal are shown.

In section 5, we estimate a simplified demand response to consistent carbon pricing, using price elasticities of demand. In the previous sections, zero price elasticity of demand was assumed. We quantify demand reductions based on standard values for price elasticity of demand for different materials. Price effects are highest for cement and aluminium due to very high direct (cement) and indirect (aluminium) emission intensities. The medium-term decrease of demand for these materials amounts to 12 percent for cement, 11 percent for aluminium, and five percent for steel.

In section 6, we approximate potential fiscal revenues for the three BCA types characterized by Ismer et al. (2020), namely, a border carbon adjustment on imports (Option I), a symmetric BCA with a reimbursement for exports (Option II), and an excise duty or climate contribution (Option III). We assume that free allocation of allowances is abolished under Options I and II, such that full carbon cost pass-through is achieved. Under Option III, free allocation continues as an instrument to address carbon leakage, while the excise charge ensures carbon cost pass-through along the value chain.

We first estimate revenues assuming no demand response. A climate contribution (excise duty, Option III) has the highest revenues (around 20.5 billion euros for the EU27), all of which would likely be collected at the EU level. An import-only BCA (Option I) has the second highest revenues (up to 18.6 billion euros). However, a significant share is subject to risks of resource shuffling, i.e., the less emissions-intensive materials produced abroad may be directed or merely allocated on paper towards the European market to reduce the liability for carbon costs. Under full resource shuffling, revenues may decline to 14.5 billion euros. The majority of these revenues would accrue to the member states due to increased auction revenues from previously freely allocated allowances. The symmetric BCA (Option II) results in the lowest net-revenues due to export rebates (8.5-14.3 billion euros, depending on resource shuffling). Factoring in the demand response estimated in section 5, we also calculate revenues under this assumption.

2 Product-level price increases along the value chain

In this section, we calculate product-level price increases due to consistent carbon pricing of cement, steel, aluminium, plastics, pulp and paper, with a focus on manufactured products. To do so, we first calculate product-level carbon intensities for about 4,400 PRODCOM[4] commodity groups, based on EU-ETS benchmarks (sections 2.1 and 2.2). We then calculate price increases for these products, which we report at an aggregate level of four different product categories, namely, basic materials, basic material products, components, and final goods (section 2.3).

2.1 Construction of product-level carbon intensity benchmarks

Here, we present our methodology for assessing the carbon content of products. Greenhouse gases (GHGs) are generally accounted for at the process level, like GHG emissions in the blast furnace (steelmaking), aluminium smelting, electricity generation, or operation of vehicles with internal combustion engine. Matching these emissions, a list of process-based emissions benchmarks was developed for the EU-ETS to form the basis of (free) allocation of emissions allowances to address carbon leakage risks (Direct emissions benchmarks for industrial processes, EU-ETS 2019/331/EU). This process-based list was complemented by electricity intensity benchmarks (EU-ETS 2012/C 387/06) and emissions intensity benchmarks for electricity (EU-ETS 2012/C 158/04) to derive indirect emission benchmarks.

Consumers, importers, and exporters deal with commodities and not with processes and therefore need product-level GHG benchmarks to work with. Embodied emissions or resources are the most common product-level supply chain indicators, they are defined as the sum of all emissions that occur in the supply chain of a commodity. We can apply this definition to calculate EU ETS-compatible material-specific carbon intensities, using simplified supply chains of commodities, EU-ETS process and electricity benchmarks, and data from life cycle databases such as ecoinvent (Wernet et al., 2016). We assign the EU-ETS benchmarks to the relevant processes to calculate and sum up the different emissions contributions (Figure 4).

[4] PRODCOM is a survey that provides statistics on the production and sale of about 4400 industrial goods and services. PRODCOM mainly covers materials, material products, and manufactured goods, but also including some industrial services (mining, quarrying and manufacturing). Annual PRODCOM statistics include both the physical volume (kg, m2, number of items, etc.) and the monetary value of production sold, imports, and exports. Products are detailed at an eight-digit level: The first four digits refer to the equivalent class within the Statistical classification of economic activities in the European Community (NACE), and the next two digits refer to subcategories within the Statistical classification of products by activity (CPA).

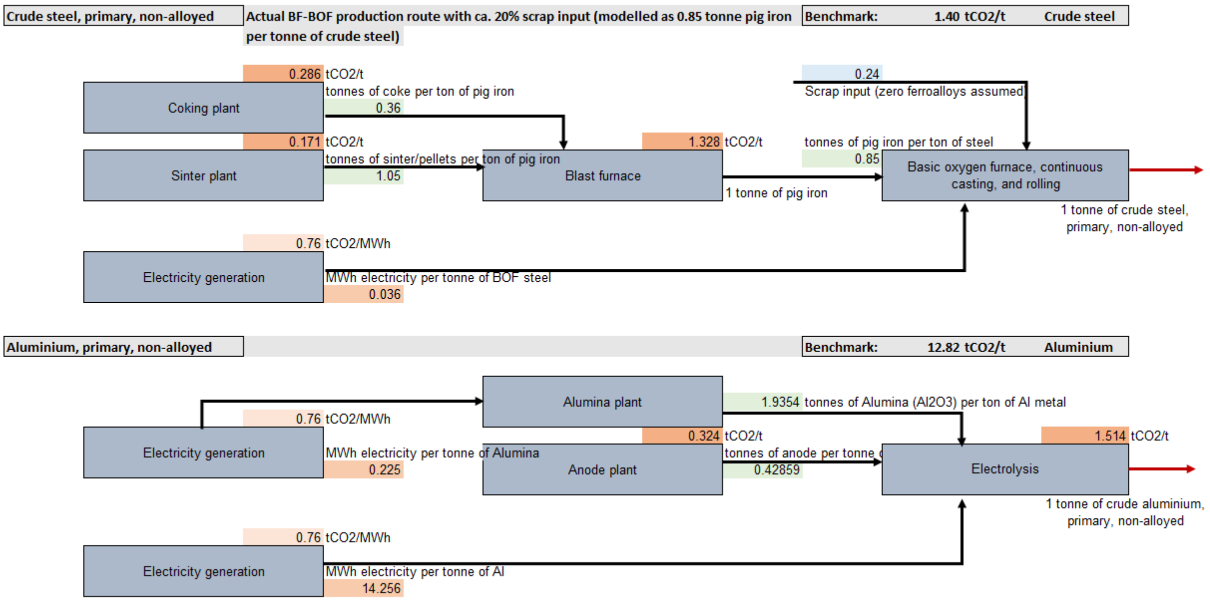

Figure 4: Construction of product-level CO_2 benchmarks with simplified supply chains

Here, the examples of crude steel (basic oxygen furnace (BOF) route with ~20% scrap input) and primary aluminium are shown. EU-ETS process and electricity benchmarks are combined with mass balance and process data.

2.2 Implications for carbon intensity of products

The resulting EU-ETS-based product benchmarks for the basic material commodities (Table 2) are in general smaller than full carbon product footprints calculated by life cycle assessment. This has two reasons. First, the supply chain scope of the simplified product-level benchmarks (Figure 4) is reduced compared to the supply chain depth of databases like ecoinvent. Second, the EU-ETS GHG benchmarks do not represent industrial averages, but well-above-the-average technology.[5]

Table 2: Total EU material production in 2019, related CO_2 benchmarks, and carbon liability per tonne created upon material production

Material	Total production, EU27, 2019, Mt	EU-ETS benchmark t CO_2-eq/t	Liability per tonne (EUR)
Steel (all)	152	1.780**	53.4
Al (all)	6.2	12.82	384.6
Plastics	116	0.902*	27.1
Pulp	20.4	0.09	2.7
Paper	82	0.308	9.24
Cement	141	0.69	20.7
Carbon price: EUR/t of CO_2	**30**		

*For PVC, a benchmark of 1.5 tonnes/tonne is applied.

** The steel benchmark decreases to 1.4 tonnes/tonne for a share of 20% scrap in primary (BOF) steelmaking (cf. Figure 4).

Production volumes include primary and secondary production except for pulp (only pulp from virgin resources was counted) and cement (virtually no recycling). Sources: World Steel Association (2020), PRODCOM industrial production statistics (Eurostat).

[5] EU ETS benchmarks are based on the average emission intensity of the 10 percent most efficient installations.

Table 2 shows a high benchmark for aluminium, which is due to the large electricity-related contribution (scope 2) that can be seen in Figure 4. The benchmark for pulp is rather low, which is a direct consequence of the low process-level benchmark as most of the energy for the pulp extraction is sourced from the lignin component of the wood.

The product level benchmarks approximate how much GHG is covered by the EU ETS in the supply chain of each material, assuming that all production steps happen in the EU. If there are no free allocations of emission allowances in the EU ETS, the total material-specific carbon costs can be calculated as GHG benchmark multiplied by the market price of a ton of CO_2 emitted. If the materials are imported and subject to either a full border carbon adjustment or an excise duty (Ismer et al., 2020), a mass-based liability that corresponds to full domestic supply chain carbon costs would be levied.

The indicator liability per tonne is calculated as the product of the product-level benchmark and the carbon price (here: 30 EUR/tonne), so that plastics, with a benchmark of 0.9 tonnes have a per-tonne-liability of 0.9*30 = 27 EUR/tonne. Total liability volumes are calculated as production volume * liability per tonne, and here, the large-quantity materials steel, plastics, and cement dominate the results, accounting for ca. 75% of all material-related carbon liabilities created at the point of production in the EU.

2.3 Implications for carbon intensity of products

2.3.1 Calculation of product-level price increases

Above, the material-related liabilities were calculated in EUR/tonne of material. These results can be used to calculate the maximum price change of products that contain these materials in a first order approximation, assuming that their composition and weight per price does not change under full carbon cost pass-through. Here, the following calculations are performed for each commodity group *c* and all basic materials *m* considered:

$$\begin{aligned}\Delta p/p\ (c) &= C\text{-}charge\ per\ kg\ (c)\ /\ price\ per\ kg\ (c)\\ &= C\text{-}price\ *\ Benchmark\ (m)\ *\ MatContent\ (m,c)\ /\ price\ per\ kg\ (c)\\ &= C\text{-}price\ *\ Benchmark\ (m)\ *\ MatContent\ (m,c)\ *\ Flow\ weight\ (c)/\ Flow\ Value\ (c)\end{aligned}$$

Where $\Delta p/p\ (c)$ is the relative price change (first order, in 1 or %) and the carbon-charge per kg of *c* is calculated as above as carbon price (*C-price*) times the material-specific *Benchmark (m)* times the material content of material m in commodity group *c* (*MatContent (m,c)*). The commodity group-specific material composition was taken from previous work (Pauliuk et al., 2016) and updated to the full list of 4,476 commodity groups. Unit prices (*price per kg of c*) can be obtained by dividing the production flow weight by the production flow value as reported for the commodity groups as part of the PRODCOM production statistics (Eurostat, 2020).

Cement has the highest carbon charge level per product price and here, price signals of up to 50 percent are possible at a carbon price of 30 EUR/tonne. Price signals for steel (primary production) are between 20 to 25 percent, those for aluminium around 17 percent (Table 3). For plastics, price changes between 5 and 7 percent can be expected and even lower values for pulp and paper. Relatively high price changes for basic material products are plausible, since these are composed of 100 percent of a certain material and have not accumulated any additional value added through subsequent fabrication and manufacturing.

Table 3: Maximum percentage price change from carbon charges at a carbon price of 30 EUR/tonne for selected basic material commodities

ProdCom/ NACEv2.2 code	ProdCom/ NACEv2.2 name	Price change [%]	Material
23511100	Cement clinker	49.3	Cement
23511210	Portland cement	28.2	Cement
24101100	Pig iron and spiegeleisen in primary forms	25.8	Steel
24102110	Flat semi-finished products (of non-alloy steel)	21.2	Steel
24421130	Unwrought non-alloy aluminium	17.6	Aluminium
20162090	Polymers of styrene, in primary forms	4.0	Plastics
20163010	Polyvinyl chloride in primary forms	6.4	Plastics
20165230	Polymers of vinyl acetate, in primary forms	3.8	Plastics
20161050	Polyethylene in primary forms	3.3	Plastics
17111400	Mechanical wood pulp	0.7	Pulp
17111200	Chemical wood pulp, soda or sulphate	0.5	Pulp

2.3.2 From commodities to product categories

In the previous section, we showed price increases for selected goods at the level of single PRODCOM commodity groups. To understand how price changes evolve as the degree of manufacturing becomes higher, we group the commodities containing basic materials into four groups.[6]

(Basic) materials: A material is either a (technically pure) substance or a mixture of substances in a physical form that can be sold and transported, such as gaseous (hydrogen, ethylene, etc.), liquid (nitric acid, gasoline) or solid (cement clinker, polyethylene granules, metal ingots etc.). Materials are either produced from raw materials (i.e., natural resources, in which case they are called primary materials) or from waste or scrap (in which case they are called secondary materials) in an industrial process during which their chemical composition is modified.[7]

Basic material products: Products which consist of one single basic material (barring additives such as alloying elements), and which are often produced in a (sometimes energy intensive) process closely coupled and performed in the same installation as the basic material production. Examples are bricks and ceramic tiles, glass bottles, steel or aluminium sheets, rods, bars, coils, profiles, etc. There are often high energy saving potentials in the process chain if the forming step is integrated with the material production, e.g., if the still hot steel can move from continuous casting directly to the hot rolling plant. Therefore, there is little incentive to perform the forming in a separate plant, and the basic material is seldom traded without a subsequent forming step.

Components (also referred to as semi-finished products): This term would refer to products made of more than one basic material or basic material product, which thus require more complex

[6] This classification builds on input from Hubert Fallmann.
[7] For example, cement clinker is result of burning, iron ores are reduced to metallic iron (pig iron), crude oil is split into its constituents by distillation, which are further refined into a wide range of basic organic chemicals, etc..

manufacturing steps. Steel sheets after surface treatment and coating, cutting and further forming (e.g. into sheets that have already the form of a car door) belong to this category. Car tyres, electrical components, or processed wood products like fibreboards are further examples. Components are usually not intended for end consumers, but are manufactured into final products.

Final products: By this term, we mean every product which is made out of components and/or further basic materials/products. In contrast to the other products in the value chain, final products are not part of other final products. This category comprises a wide range of products, including cars, mobile phones and television sets, but also simpler things such as carton-packaged aluminium foil on a roll ready for sales to end consumers.

Some products can plausibly be assigned to several groups, e.g., tissue paper or metal casting applications or metal furniture, which are both a basic material product and a final product. For the purpose of material production-based carbon liabilities, pure material products are classified as more "upstream" (i.e., basic material products) in order to reflect that such goods (with high cost increases due to carbon pricing) can easily and would likely be included in the scope of a border carbon adjustment.

2.3.3 Price increases for product categories

Figure 5 shows the number of PRODCOM commodity groups by relative price change (resulting from a carbon price of 30 EUR/t), sorted into the four categories basic material, basic material product, component and final product as defined above. Here, each group's price change is counted irrespective of the group's economic significance (total value or volume). In section 3, we extend the analysis to consider the value of commodity groups and link price changes to value added, in order to assess carbon leakage risks for European manufacturers.

The relative price changes of commodities of a higher degree of manufacturing tend to be smaller than the ones of basic materials. This is due to the increasing relevance of cumulative value added with a higher degree of manufacturing and – for some supply chains – a decline of the share of the six materials studied in products along the supply chain, as other materials, like wood or copper, are added. For the basic materials, price changes range from 0.1 to 50 percent, with the highest value (around 50 percent) for cement clinker and many groups ranging between one and seven percent. For the basic material products, the typical price changes also range from ca. 0.5 to seven percent. For component and final products, most groups show a price change of below 0.5 percent, with many even below 0.1 percent. This illustrates the dominance of value added over material-related costs in the price of these commodities.

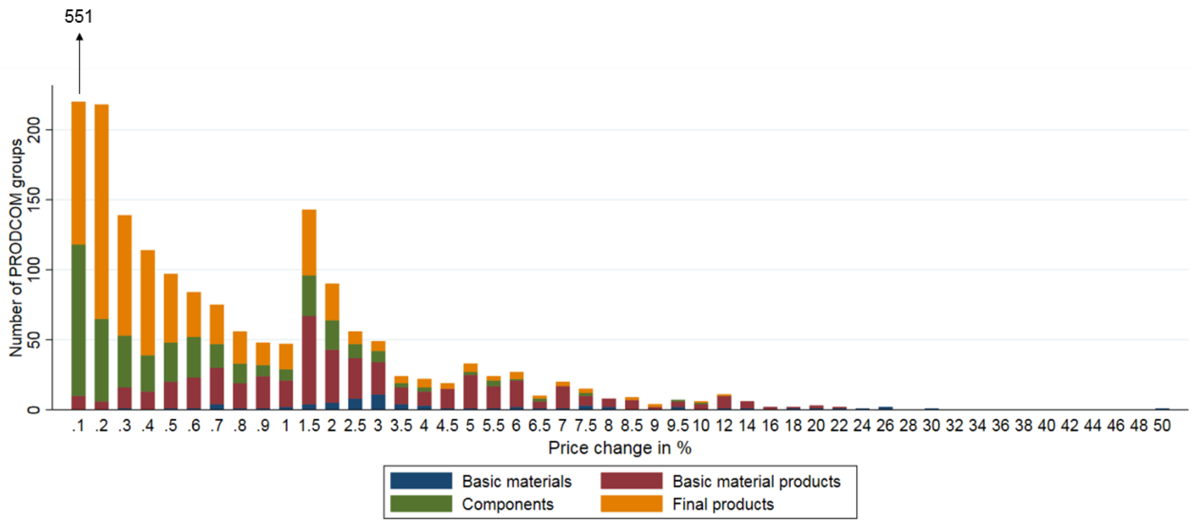

Figure 5: Distribution of PRODCOM trade groups by price increase at a carbon price of 30 EUR/t

Not depicted in the graph are 1,061 prodcom groups with price increases close to zero.

3 Carbon cost differences as indicator for carbon leakage risks

In this section, we quantify carbon leakage risks under an import-only BCA combined with full auctioning. Such an import-only BCA may have a limited coverage of the value chain, in order to limit administrative costs and avoid more than single charging of products in the case of value chains that are integrated across borders (Ismer et al., 2020). Moreover, an import-only BCA has an impact on relative costs of domestic producers in external markets (Evans et al., 2020). This may trigger two potential sources of increased carbon leakage risk for European manufacturers.

First, under any border carbon adjustment with a limited coverage of the value chain, European producers selling products not included in the BCA in the European market would face higher carbon costs on their inputs than their international competitors. Hence, they may reduce domestic production and emissions at the expense of foreign production and emissions.

Second, in many cases manufacturers export parts of their domestically produced goods, while facing price competition on international markets. In an import-only BCA without rebate for exports. Higher carbon costs might therefore trigger a reduction of exports of domestic production and corresponding emissions at the expense of an increase in non-EU production and emissions.

3.1 Definition: Carbon cost increase relative to value added

To identify which industrial activities may be exposed to a risk of carbon leakage through the two channels mentioned above, we compute the ratio of carbon costs relative to gross value added (GVA) for 4,400 product categories along the value chain. In principle, carbon cost increases of products can be depicted relative to a variety of reference values. Product prices are commonly applied as reference values. However, for a comparison across different firms and sectors, the results will also reflect the large variations of the share of input costs not under control of firms. Hence, we use gross value added as a reference value for carbon cost increases. This follows the approach of most assessments of carbon leakage risks, and corresponds to the indicator used to assess carbon leakage risk under the EU ETS until 2020 for primary material producers (Directive 2003/87/EC, Sato et al., 2015).

In line with the threshold defined in the EU ETS Directive, we consider product categories to be potentially at risk of carbon leakage, where carbon costs relative to GVA exceed five percent.[8] We also include the second criteria under the EU ETS Directive in our analysis, namely a trade intensity[9] of at least ten percent.

To compute the values, we calculate first carbon cost increases relative to sales value due to consistent carbon pricing of basic materials at a carbon price of 30 EUR/t for all PRODCOM commodity groups, as described in section 2.3.1. We divide this price increase by a NACE-specific ratio of gross value added (GVA) to turnover.[10] The results vary largely across the four product categories. The highest increases of carbon costs relative to GVA occur for basic materials and basic material products, but there are also components and final products with high increases of costs relative to GVA (Table 4).

Table 4: Carbon cost increase (in %) relative to GVA in different product categories

	Mean	Median	Max	Min	Standard deviation
1: Basic materials	23.0	11.2	155.8	0	33.9
2: Basic material product	8.8	2.4	108.9	0	15.1
3: Components	1.5	0.7	32.5	0	3.7
4: Final products	1.3	0.2	45.0	0	3.6

The statistics (in percent) are calculated for a carbon price of 30 EUR/tonne under the assumption of full carbon cost pass-through (i.e. without free allocation of allowances).

Our analysis provides only an indicator for the upper bound of potential carbon leakage risks for a number of reasons. First, we assume that the carbon costs are fully additional. This can be imagined as a situation with no carbon cost pass-through where the phase-out of free allocation leads to consistent carbon pricing, or an increase of an existing carbon price. Second, our assessment of carbon leakage risks assumes that EU producers incur full carbon costs for their inputs, while competitors do not face similar carbon costs. Third, the analysis does not assess the response strategy of European firms. This may involve enhanced material and carbon efficiency, accepting a reduction of profit margins, or increasing the sales prices at the risk of declining market shares compared to other international producers.

[8] The 5% threshold for the assessment of carbon leakage risks in Art 10a(15) of Directive 2003/87/EC has been replaced for the period post-2020 by a new indicator based on the product of trade intensity and emissions intensity (emissions divided by gross value added).

[9] Trade intensity is defined as the sum of the value of imports and exports, divided by the EU market size (domestic sales plus imports).

[10] Gross value added is not available at the PRODCOM level. We therefore calculate the average GVA to turnover ratio at the NACE 4 level, assuming that this is constant for all PRODCOM commodity groups that belong to the same 4-digit NACE sector.

3.2 Potential carbon leakage risks linked to domestic sales

Border carbon adjustment mechanisms covering only some product categories, like for example basic materials and basic material products, will in combination with full auctioning increase input costs for domestic producers of components and final products. Figure 6 depicts 240 billion euros worth of domestic sales of internationally traded components and final goods with cost increases relative to GVA of more than five percent at a carbon price of 30 EUR/tonne. [11] For a carbon price of 75 euros, this sales volume would increase to 760 billion euros, (or 15 percent of overall manufacturing). This sales volume could thus be at risk of carbon leakage, if higher input costs for domestic producers result in a relocation of production and thus emissions to other countries. Table 5 depicts the corresponding values also for other product categories.

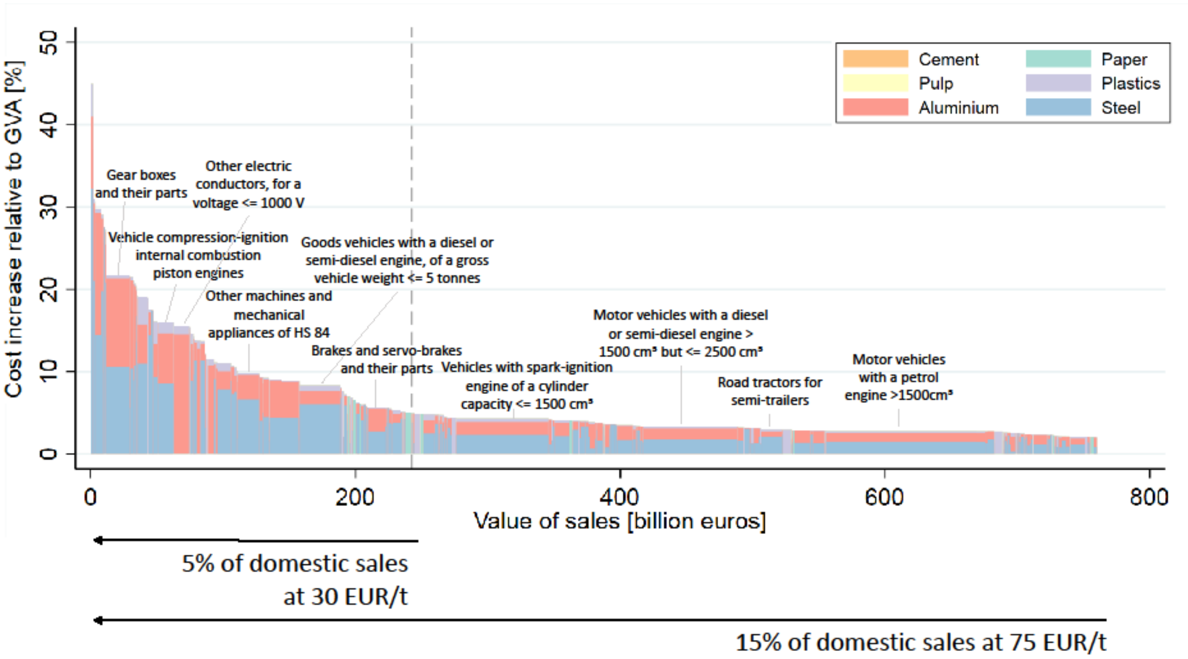

Figure 6: Components and final products potentially at risk of carbon leakage under a BCA that covers only basic materials and basic material products

Based on EU-27 PRODCOM manufacturing data (NACE codes 10-33) from 2019. Cost increases relative to GVA are based on a carbon cost of 30 EUR/t and benchmarks from section 2.2, under the assumption of full carbon cost pass-through.

Considering only the carbon cost increase and not the trade intensity, sales of components and final products with a cost increase relative to GVA of more than five percent increase by 10 percent, to 266 billion euros and 817 billion euros for a carbon price of 30 and 75 EUR/t.

[11] Our calculations are based on 2019 EU-27 PRODCOM data, downloaded from Eurostat. In case the value of sales or the value of exports are missing in the 2019 data, we use 2018 values, where available. Moreover, for two percent of the commodity groups, we calculate the trade intensity indicator with 2018 data due to missing values in the 2019 statistics. We also include 48 commodity groups, for which the costs relative to GVA indicator is available, but the trade intensity indicator cannot be calculated due to missing values for imports or exports.

Table 5: Potential carbon leakage risks in manufacturing – domestic sales

	Number of PRODCOM categories	Value of sales [mEUR]	Value of sales with potential carbon leakage risks at 75 EUR/t [mEUR]	Value of sales with potential carbon leakage risks at 30 EUR/t [mEUR]
Not relevant	1,313	1,681,325	-	-
Basic material	90	148,105	110,691	100,269
Basic material product	768	882,421	472,879	317,721
Component of product	743	1,076,112	209,598	94,868
Final product	1,480	1,364,615	550,256	147,647

3.3 Potential carbon leakage risks linked to exports

Under an import-only BCA in combination with full auctioning (Option I), European exporters would face full carbon costs and might thus lose market share to other producers not exposed to carbon costs, potentially contributing to relocation of production and emissions. Almost 190 billion euros worth of exports, or 10 percent of the total value of exports in manufacturing, would face an increase of costs relative to GVA of at least five percent at a carbon price of 30 euros (Table 6 and Figure 7). This share would increase to 23 percent (almost 450 billion euros) at 75 EUR/t.

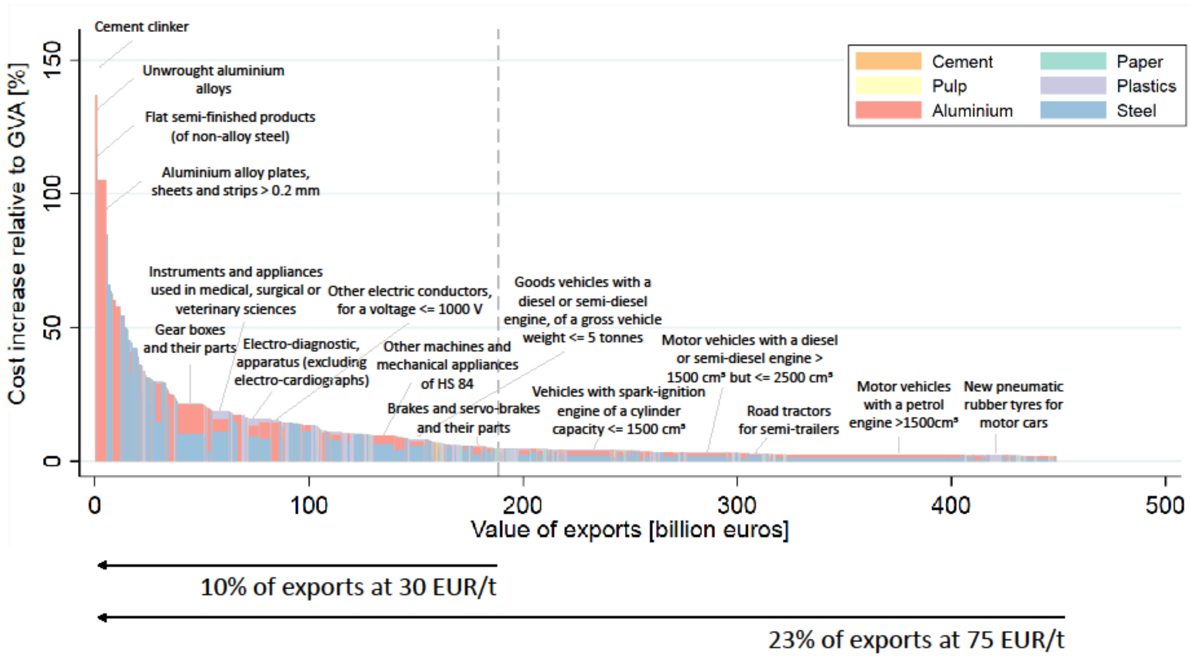

Figure 7: Products potentially at risk of carbon leakage in export markets under a BCA without reimbursement for exports

Since product groups that are exported are typically trade-intensive, the second carbon leakage criterion of trade intensity is largely met. Without an application of this criterion, the exports with a cost increase relative to GVA of more than five percent alone would increase by 2.5 percent.

Table 6: Potential carbon leakage risks in manufacturing under BCA without reimbursement for exports

	Number of PRODCOM categories	Value of sales [mEUR]	Value of sales with potential carbon leakage risks at 75 EUR/tonne [mEUR]	Value of sales with potential carbon leakage risks at 30 EUR/tonne [mEUR]
Not relevant	1,313	519,187	-	-
Basic material	90	36,662	29,145	24,857
Basic material product	768	186,577	106,889	63,880
Component of product	743	407,802	71,004	33,145
Final product	1,480	771,958	241,886	66,617
Total manufacturing	4,394	1,922,186	448,925	188,499

While the EU is a net importer of many basic material and basic material products, it also exports 89 billion euros of basic material and basic material products, for which an import only BCA would result in cost increases of more than five percent relative to GVA at a carbon price of 30 EUR/t. The sectors with the highest share of production at risk from carbon leakage for exported materials are aluminium (almost half of the production is exported, cf. Table 7), pulp and paper (31 and 21 percent export share, respectively), and steel (18 percent exports).

Table 7: Production, imports and exports of selected basic materials

	Total production [Mt]	Imports [Mt]	Exports [Mt]	Export share [%]
Cement	152	5,4	11,9	8
Steel	159	47,0	29,7	19
Aluminium	7	8,2	3,3	49
Plastics	119	24,2	21,4	18
Pulp	21	8,1	6,3	31
Paper	88	7,6	20,3	23

4 Distributional impacts

If carbon prices are passed on to product manufacturers and the construction sector and, ultimately, from there to the final consumers or purchasers of products, buildings, and infrastructure, then this will impact consumers and may have distributional implications. While the accurate estimation of price changes of final consumption with high commodity resolution is impossible given the interference of the carbon charge with profit margins, demand changes, material substitution and reduction, and technological change, a first order estimate can be given. For this estimate, we compute the 'price signal', which is the maximum carbon charge per disposable income due to price changes of commodities along the value chain. The estimate assumes that quantities do not change, meaning that industries do not improve the efficiency of their choice of materials in products and consumers do not shift demand. Due to this simplification, this calculation leads to an upper boundary of the expected price changes.

With consumer expenditure data by income decile, we can compute price signals for different income groups (Figure 8). We compute these price signals for a case study for Germany by constructing the global supply chains of a detailed inventory of consumer expenditure (DESTATIS, 2015) with the EXIOBASE multi-regional global input-output model (Stadler et al., 2018), using the readily available refinement and matching done by Hardadi et al. (2020). We first estimate the EU27 average price changes of seven EXIOBASE basic commodity groups (one for each of the different materials studied), using the methodology from section 2, and then apply EXIOBASE to propagate these price signals through the supply chains that contain these materials until the point of final consumption.

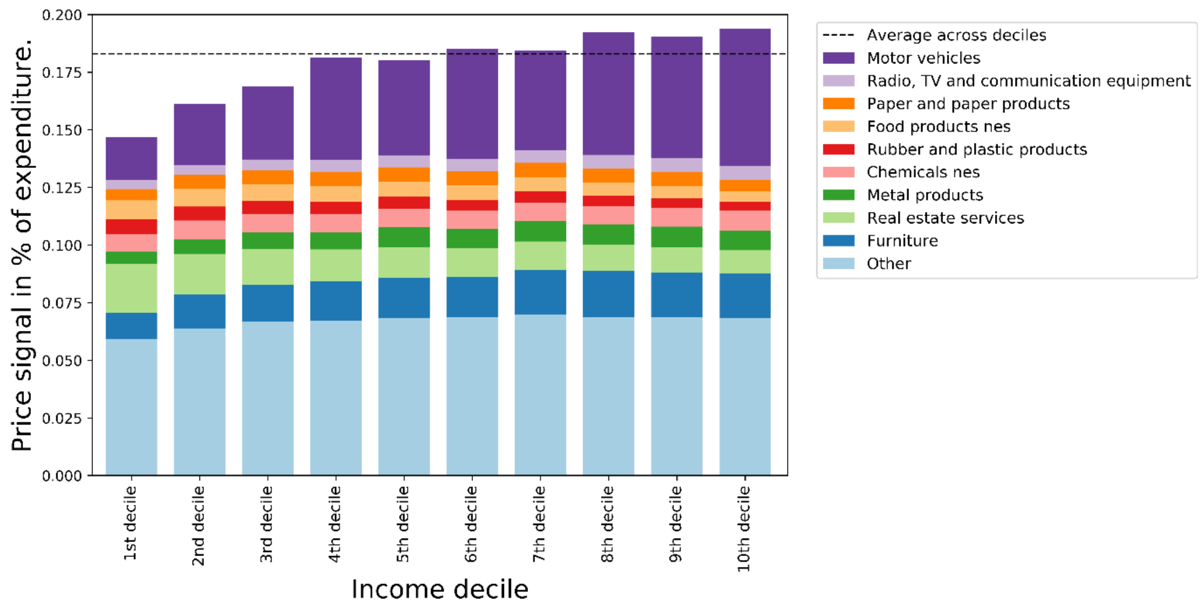

Figure 8: Carbon cost related price increase for German households by income decile

The total price signal for households by income decile due to full carbon charging of basic material production is small and progressive: Figure 8 shows that the price signal due to the carbon charge levied on basic material production both in the EU27 and the supply chain of imported material commodities is below 0.2 percent and increases by about one third with disposable income across all income groups.[12] That means that high income households would receive a carbon charge signal corresponding to relatively larger share of their disposable income than low income households. Consistent carbon pricing of materials therefore does not exhibit the regressive behaviour common to electricity charges and gasoline taxes (Wier et al., 2005; Bureau, 2011). Instead, it would contribute to a reduction of income-related inequality, resulting in a small but positive potential synergy with the societal and policy goal of inequality reduction.

The price change signal trend across income deciles varies with the consumption groups. Due to the homogeneity of the 163 expenditure groups in the supply chain model, the carbon footprint and related price signal *per unit of expenditure* is the same across income deciles. Hence, the distributional changes seen here are a direct consequence of the variations across income deciles in the share of disposable income spent on each group. Most remarkably, increases in expenditure on motor vehicles vary substantially across income deciles, i.e., richer households spend relatively more on cars. Moreover, motor vehicles show a relatively high price change (0.93% on average), which results in that most of the progressive trend of the price change can be attributed to motor vehicle purchases (Figure 8). Furniture, metal products, and all other consumption categories together also show a slightly progressive trend, whereas the trend for real estate services is clearly regressive, but not enough to dominate the overall result.

The price signal in the largest expenditure groups is well below two percent: It is highest for metal products (1.4%), followed by paper and paper products (1.2%), while the other major expenditure categories displayed in Figure 8 have price changes of less than one percent on average. We therefore expect that the direct impact of consistent carbon pricing of materials on household consumption choice would not be large. From a material efficiency point of view, this is not a major issue, as most material choice decisions are not made by final consumers, but by component manufactures, where price signals are stronger, as the ratio of the carbon price increase to the total value added is larger for products with a high degree of manufacturing (see sections 2 and 3).

5 Estimation of potential demand response

In this section, we estimate a simplified demand response to consistent carbon pricing, using price elasticities of demand. Price increases of basic materials due to a consistent carbon pricing will likely have an effect on material demand, for example due to a more efficient use of material in production. All preceding analysis ignored that price changes will trigger a demand response. However, economic theory and empirical estimates suggest that the demand for commodities is price responsive. While estimated price elasticities vary by sector and over time (e.g. Röller and Steen, 2006; Smale et al., 2006; Demailly and Quirion, 2008; Pollitt et al., 2020), the assumption of a completely inelastic demand is not realistic. Following Pollitt et al. (2020), we therefore assume a demand elasticity of -0.5 as the basis for our estimates for medium-term demand responses for the different materials.

[12] Even this small effect is likely an over-estimation of the actual effect on household expenditure of the implementation of a BCA or an excise, since there is likely to be some existing carbon cost pass-through already today. Furthermore, in the mid-term, demand response (e.g. due to increased material efficiency) may reduce the price effects.

We find that demand reductions of five percent for steel, 11 percent for aluminum, and 12 percent for cement are triggered by a carbon price of 30 Euro/t over the medium term (Table). To allow for a comparison, we also depict the price and demand impact an additional carbon price would have on gasoline in Table . The coverage of refining emissions alone would have a negligible impact. Only if end-of-life emissions from incineration of gasoline are covered, a demand impact of seven percent would be observed. This illustrates the importance of also considering embodied emissions. In the case of gasoline, these emissions are covered through national excises on fuels.

For plastics, the majority of emissions are not process related, but linked to an end-of life incineration, as is the case for gasoline. In the case of plastic, the carbon costs from incineration are usually exempt from EU ETS charges. Even where incineration plants are not exempt from the EU ETS, the costs incurred at the end of a product lifetime are not reflected in purchasing prices. Thus, carbon costs do not trigger material efficiency and do not allow for a fair inter-material competition. If end of life emissions were fully priced, and if the corresponding carbon costs would be translated to purchase decisions (for example through advanced disposal fees), then a demand impact of ten percent could be anticipated at a demand elasticity of -0.5.

Table 8: Demand response for basic materials

	Price of material EUR/t	Emissions/t production	Emissions/t incineration	% cost increase prod.	% cost increase full	% demand response medium-term
Steel	500	1.78		11		-5%
Cement	70	0.69		30		-12%
Aluminium	1500	12.82		26		-11%
Pulp	750	0.09		0.4		-0.2
Plastics	500	1.5	2.5	9	24	-10%
Gasoline	1500	0.0295	3.1	0.6	7	-3%

The calculations are based on a CO_2 price of 30 EUR/t, as well as a medium-term demand elasticity of -0.5 and a longer-term demand elasticity of -1. Emissions per tonne of production are equivalent to the benchmarks developed in Table 2. The low demand response for pulp reflects that emissions from burning biomass (the bulk of emissions) are not covered under the EU ETS. The gasoline emissions intensity of 0.0295 equals the EU-ETS refining benchmark, the price assumes a weight of 0.75 kg/l. Full cost increases and the demand elasticities include end-of-life emissions from incineration.

6 Fiscal revenues

Following Ismer et al. (2020), we estimate additional public revenues for the EU27 and its member states that would result from the implementation of the following BCA designs, namely (i) a shift to full auctioning in combination with an import only BCA on basic materials and basic material products (import-only BCA, Option I); (ii) a shift to full auctioning in combination with a BCA on imports and exports of basic materials included in basic material products, components and final products (BCA on imports and exports, Option II); and (iii) a climate contribution (excise duty, Option III) levied on all domestic production not exported and imports of basic materials imported, including basic material products, components and final products with significant shares of the relevant basic materials.

6.1 Assumptions

We include revenues from the inclusion of cement, steel, aluminium, pulp and paper and plastics in our revenue estimates. For each material, the charge is set at the same reference values as described in section 2.3.1 for all three options. For the estimation of additional auction revenue in Options I and II, we assume that allowances needed for the production of materials beyond the reference value were already auctioned in the past. The additional auction revenues thus equal the volume of (primary) production multiplied with the material-specific reference value and the EU ETS price.

For steel and aluminium, we calculate additional auction revenues based on the share of primary production only.[13] Additionally, in the case of steel, we assume that 20 percent of scrap is used in primary steelmaking (basic oxygen furnace, BOF).[14] Since the allocation volume is today already adjusted for the share of scrap and hence scrap does not benefit from free allowance allocation, additional auction revenues are reduced in line with the scrap share.

For Options I and II (import-only and symmetric BCA), we assume that all imported products contain only primary materials and are thus fully liable to the border charge.[15] However, imported steel from the BOF route also contains scrap, which we account for by lowering the benchmark by about 20 percent (mirroring the assumption on domestic primary steelmaking). For the calculation of the export rebate in Option II, we assume that exports only comprise primary production of steel and aluminium.[16]

For the excise (Option III), the liability for the climate contribution is created at the benchmark reference level both for imports of primary and secondary produced material, i.e. independently of the specific production process. Globally, any additional tonne of material demand will trigger an additional tonne of primary production, since in aggregate no surplus scrap capacity is available. Consequently, we do not apply any discount to the excise charge for the scrap share used in primary production processes.

Some EU member states offer power price compensation up to a maximum allowed under EU state aid guidelines for EU ETS indirect cost compensation. This support would probably be abandoned in Options I and II, but the scale of savings is difficult to estimate as approaches differ across EU

[13] Around 60 percent of the total EU27 production of 152 million tonnes of steel is production from basic oxygen furnaces (World Steel Association, 2020), which is mostly primary steel but also contains around 20 percent re-melted scrap. For aluminium, 1.6m tonnes (26 percent of EU aluminium production) is primary aluminium. We do not differentiate between primary and secondary production for plastics and paper. This leads to an overestimation of auction revenues under the import-only BCA (i) and the BCA on imports and exports (ii). For pulp (only wood-based pulp was included here) and cement (virtually no recycling), there is no recycled content.

[14] We thank Hubert Fallmann for pointing this out. The assumption on the use of scrap reduces the benchmark from 1.78 to 1.4 tonnes/tonne (cf. Table 2). See also Broadbent (2016) on the use of scrap as iron input in the BOF route.

[15] However, if non-European producers can demonstrate that they do export secondary production to Europe, actual revenues would be lower. Our estimates for the revenues from imports under Options I and II are therefore an upper bound.

[16] Exported steel consists of more higher-value (primary) steel. Moreover, if incurred carbon costs are refunded for exports, EU producers have an incentive to export steel from more carbon intensive primary production.

member states on whether and at what level to offer such an indirect cost compensation. Our estimates thus do not reflect potential reduced expenditures under Options I and II. Our estimates thus do not reflect potential reduced expenditures under Options I and II for electricity-intensive processes, such as primary aluminium production (26 percent of the total EU27 aluminium production) and secondary steel production in electric arc furnaces within the EU (around 40 percent of total steel production).

For a BCA, a significant share of imports could be subject to risks of resource shuffling, i.e., the less emissions-intensive materials produced abroad may be directed or merely allocated on paper towards the European market to reduce carbon costs. The scale of potential risks from resource shuffling under Options I and II are approximated for aluminium and steel. For the lower bound of revenues for aluminium, we assume that only 80 percent of the embodied emissions in basic materials, basic material products, components and final goods are liable to an import charge, because of the opportunity to source or attribute the production of aluminium to clean electricity.[17] For the lower bound of the revenue estimates for steel, we assume that the corresponding import liability may be reduced by up to 50 percent.[18] The upper bound of the revenue estimate assumes no resource shuffling takes place at all.

6.2 Results

We estimate revenues for two demand scenarios. First, in section 6.2.1, we estimate revenues assuming zero demand elasticity. Second, in section 6.2.2, we assume a demand elasticity of -0.5, which leads to a reduction of demand for basic materials in response to price increases due to consistent carbon pricing (Table).

The revenues for the excise on domestic production, as well as additional auction revenues for an inelastic demand are shown in Table 8, which is a simple extension of Table 2 in section 2.2. Table 9 and Table 10 depict the charges created for imports and exports of basic materials and basic material products, as well as components and final goods (for Options I and II, which include a full coverage of the value chain).

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[17] Electricity plays a major role in the production of aluminium. According to EU ETS benchmarks for free allocation and power price compensation, direct emissions of aluminium production are 1.5 t CO_2/t material, and indirect emissions from electricity use are 14.3 MWh/t * 0.465 t CO_2/MWh. This means that 81.6% of total emissions are electricity-related, which can be avoided by fully attributing zero carbon electricity to aluminium production.

[18] Resource shuffling opportunities for steel depend on the production process. Long products are typically produced by electric arc furnaces (EAFs), where a major share of the carbon costs charged by a BCA can be avoided by attributing renewable electricity to the production of EAF steel. More high-value and high quality flat products, on the other hand, are typically produced by the basic oxygen furnace (BOF) route. Even for this production process, there are some opportunities for resource shuffling due to greening electricity use. Additional opportunities for resource shuffling exist, for example by increasing the scrap share in BOF production. This would lower the carbon intensity charged by a border carbon adjustment, but not necessarily lower global emissions, since a global scarcity of scrap implies this increased demand for scrap would have to be met by additional primary production.

Table 8: Excise charge created based on EU production

Material	Total production, EU27, 2019, Mt	EU-ETS benchmark t CO_2-eq/t	Liability per tonne (EUR)	Total charge created within EU27 (MEUR)
Steel (all)	152	1.780	53.4	8117
Al (all)	6.2	12.82	384.6	2385
Plastics	116	0.902*	27.1	3139
Pulp	20.4	0.09	2.7	55
Paper	82	0.308	9.2	758
Cement	141	0.69	20.7	2919
Carbon price: EUR/t of CO_2	**30**		**Sum**	**17373**

*For PVC, a benchmark of 1.5 tonnes/tonne is applied.

Production volumes include primary and secondary production except for pulp (only pulp from virgin resources was counted) and cement (virtually no recycling). Sources: World Steel Association (2020), PRODCOM industrial production statistics (Eurostat).

Table 9: Import-related charge, by group

Product category	Steel	Aluminium	Plastics	Pulp	Paper	Cement	Sum
0: not relevant	0	0	0	0	0	0	0
1: Basic material	856	2113	385	21	0	109	3484
2: Basic material product	2991	1142	375	0	50	5	4563
3: Components of products	470	538	64	0	0	0	1072
4: Final good	1254	664	338	0	18	0	2274
Sum 1-4	5571	4457	1162	21	68	114	11393

In million euros.

Table 10: Export-related charge, by group

Product category	Steel	Aluminium	Plastics	Pulp	Paper	Cement	Sum
0: not relevant	0	0	0	0	0	0	0
1: Basic material	122	133	463	18	0	310	1046
2: Basic material product	2927	1009	303	0	127	17	4383
3: Components of products	384	427	100	0	0	0	911
4: Final good	1084	538	182	0	104	0	1908
Sum 1-4	4517	2107	1048	18	231	327	8248

In million euros.

6.2.1 Revenues assuming inelastic demand

Figure 9 graphs potential revenues of different forms of border carbon adjustments, as well as an excise duty, under the assumption of an inelastic demand for the EU27.

The excise duty would generate the highest revenue total of around 20.5 billion euros for the EU27. Revenues are roughly split in half between an excise on domestic production and imports from outside of the EU. Since free allocation is continued, there are no additional revenues from additional auctioning.

The import-only BCA on basic materials and basic material products generates the second-highest revenue (up to 18.6 billion Euros). More than 60 percent of this revenue comes from additional auctioning at the level of the EU member states. Additional revenues mainly come from aluminium, steel and plastics. However, a significant part of this revenue is at risk of resource shuffling, so total revenues may also be much lower: Under full resource shuffling, revenues may decline to 14.5 billion euros (striped columns in Figure 9).

The BCA with export reimbursement has the lowest revenue (up to 14.3 billion), due to the existence of export rebates. Although revenues partially increase due to an increased coverage of the value chain, the export reimbursement decreases overall revenues by more than this increase relative to the import-only BCA. Overall revenues are lower than for the excise even in the case of no resource shuffling primarily because additional auction revenues accrue only for the share of primary production for steel and aluminium, whereas the excise charge is independent of the production process.

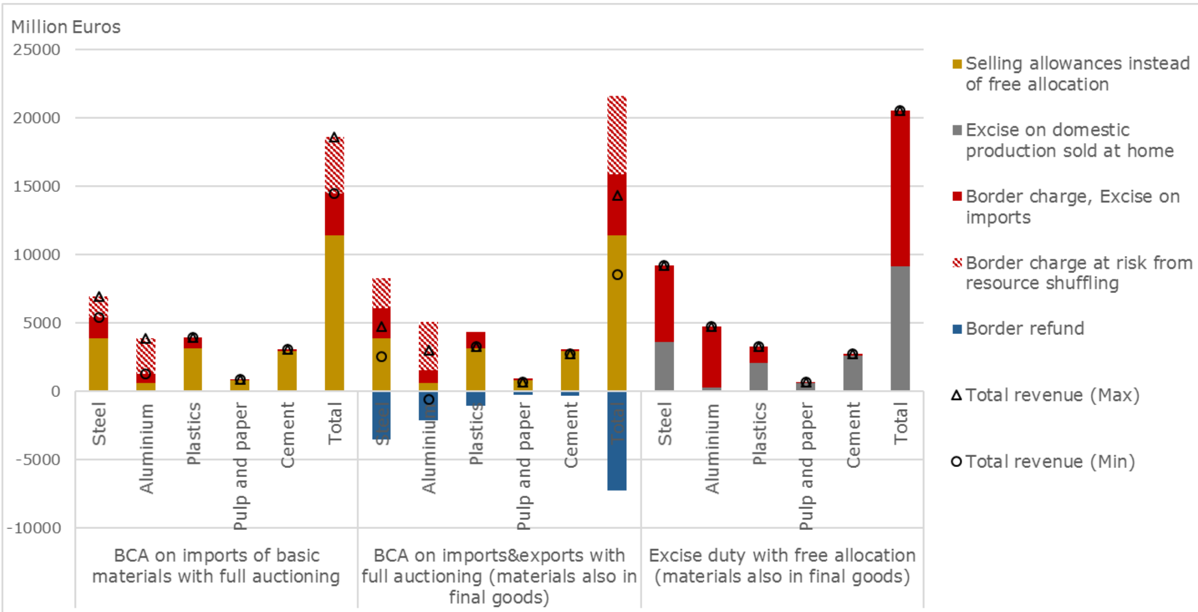

Figure 9: Potential annual revenues under different types of border carbon adjustments with inelastic demand

Calculations are based on EU27 2019 trade flow data, assuming a CO_2 price of 30 EUR/t. Export reimbursements (blue column) decrease the net revenue in the BCA on imports and exports.

6.2.2 Revenues with demand response

For the calculation of revenues with a demand elasticity of -0.5, we assume that the reduction of demand applies equally for domestically produced materials and imports. We also assume there are no effects of reduced demand for EU allowances on the ETS price, which remains at 30 EUR/t.

Figure 10 graphs the results. The revenue from the excise (Option III) decreases by around one billion euros, to 19.6 billion euros. The excise continues to generate the highest overall revenue. Some of the decrease of excise revenue is offset by an increase in auctioning revenues, since a reduction in material production leads to a decrease in free allowance allocation and thus triggers an increase in allowances available for auctioning.[19]

The BCA revenues decrease relatively less, since auction revenues are not directly affected by a decrease of primary production resulting from a demand response, as long as the allowance price remains unchanged. Since the auction revenues make up the bulk of revenues for the import-only BCA (Option I), overall revenues decrease only slightly as a result of lower import demand: Revenues are estimated in the range of 14.2 to 18 billion euros, depending on the scale of resource shuffling. For the BCA on imports and exports (Option II), the border refund for European exporters of roughly 6.7 billion euros means that total revenues of a maximum of 14 billion euros are lowest.

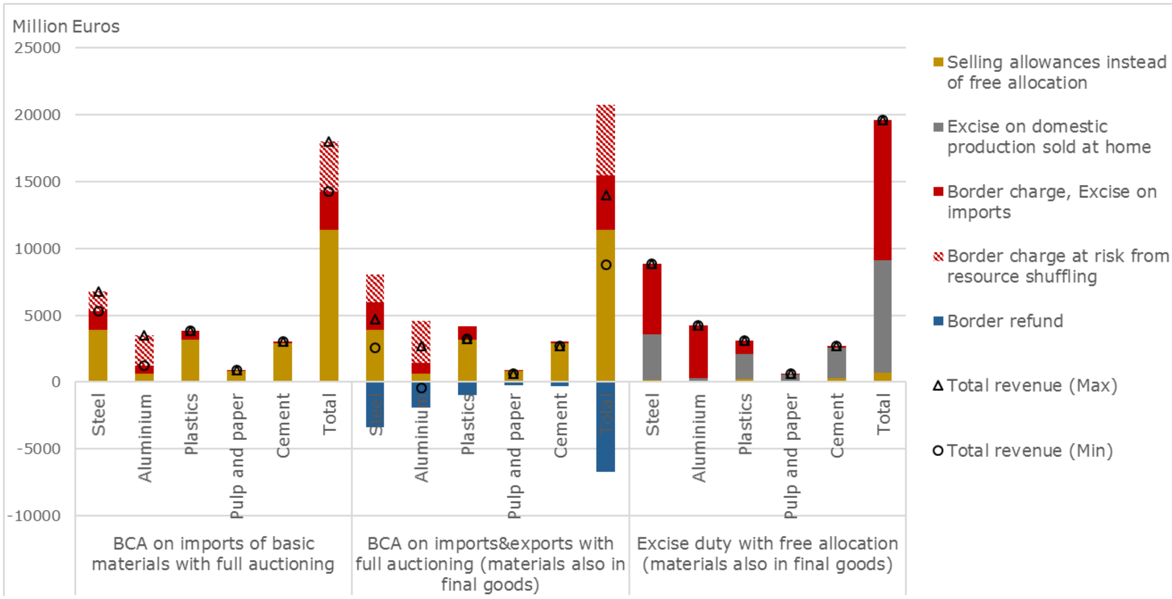

Figure 10: Potential annual revenues under different types of border carbon adjustments with elastic demand

Calculations are based on EU27 2019 trade flow data, assuming a CO_2 price of 30 EUR/t. Export reimbursements (blue column) decrease the net revenue in the BCA on imports and exports. We assume a demand elasticity of -0.5.

7 Conclusion and outlook

This paper contributes to the discussion on carbon pricing and border carbon adjustments based on an estimation of product-level price increases.

This allows for an assessment of two potential carbon leakage risk channels in the context of border carbon adjustment mechanisms. First, if imports of basic materials are only covered for part of the value chain, then domestic producers in later stages of the value chain will incur higher carbon costs on inputs than international producers, but compete in a common product market. This effect is especially pronounced if only imports of basic materials are covered, but also of concern in the case of import coverage of basic materials and basic material products. In the latter case, at a carbon price of 30 EUR/t, 242 billion euros worth of domestic sales of component and final product are subject

[19] We assume that the overall ETS cap is (at least in the short term) not affected by the decrease in production.

to a carbon cost increase relative to GVA of more than five percent. This equates to five percent of the total value of sales in the manufacturing sector.

Second, if a border carbon adjustment mechanism only covers imports then domestic producers may face higher costs and lose market share to foreign producers in export markets, resulting in a relocation of production and emissions. We show that for ten percent of the total value of exports in manufacturing (almost 190 billion euros), the cost increase relative to GVA would be above five percent at a carbon price of 30 EUR/t. In all instances, the estimated scale of activities at risk of carbon leakage is only a rough estimate, as it ignores other factors that may limit carbon leakage risks, like for example linkages along the supply chain through customer relationships and joint R&D.

Third, we look at the distributional consequences of consistent carbon pricing for basic material production. We find that price signals for final consumers are progressive. This contrasts with other forms of carbon pricing such as energy taxes, which are typically regressive. Moreover, at a price of 30 EUR/t, distributional consequences are limited: Household expenditures (assuming no demand response) would increase only marginally, namely below 0.2 percent of disposable income on average. This implies that the corresponding incentive to reduce or substitute consumption is small for final consumers. The main impact of a consistent carbon pricing is therefore expected in the value chain, where the share of material content is higher and manufacturers therefore have an incentive to use carbon-intensive materials or products more efficiently, or substitute to lower-carbon alternatives.

Finally, we estimate revenues to be expected from a consistent carbon pricing of the materials steel, cement, aluminium, plastics, pulp and paper are higher for an excise (Option III) than for an import-only BCA (Option I) or a symmetric BCA (Option II). Without demand response, total excise revenues equal 20.5 billion euros, compared to 14.5-18.6 billion (import-only BCA) and 8.5-14.3 billion (symmetric BCA), depending on the degree of resource shuffling.

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References

Bertram, C., Luderer, G., Pietzcker, R.C., Schmid, E., Kriegler, E., Edenhofer, O., 2015. Complementing carbon prices with technology policies to keep climate targets within reach. Nat. Clim. Change 5, 235–239.

Böhringer, C., Rosendahl, K.E., Storrøsten, H.B., 2017. Robust policies to mitigate carbon leakage. J. Public Econ. 149, 35–46.

Branger, F., Ponssard, J.-P., Sartor, O., Sato, M., 2015. EU ETS, free allocations, and activity level thresholds: the devil lies in the details. J. Assoc. Environ. Resour. Econ. 2, 401–437.

Branger, F., Quirion, P., 2014. Would border carbon adjustments prevent carbon leakage and heavy industry competitiveness losses? Insights from a meta-analysis of recent economic studies. Ecol. Econ. 99, 29–39. doi:10.1016/j.ecolecon.2013.12.010

Branger, F., Quirion, P., Chevallier, J., 2016. Carbon Leakage and Competitiveness of Cement and Steel Industries Under the EU ETS: Much Ado About Nothing. Energy J. 37, 109–135. doi:10.5547/01956574.37.3.fbra

Broadbent, C., 2016. Steel's recyclability: demonstrating the benefits of recycling steel to achieve a circular economy. Int. J. Life Cycle Assess. 21, 1658–1665.

Bureau, B., 2011. Distributional effects of a carbon tax on car fuels in France. Energy Econ. 33, 121–130.

Carruth, M.A., Allwood, J.M., Moynihan, M.C., 2011. The technical potential for reducing metal requirements through lightweight product design. Resour. Conserv. Recycl. 57, 48–60.

Cendra, J. de, 2006. Can Emissions Trading Schemes be Coupled with Border Tax Adjustments? An Analysis vis-à-vis WTO Law 1. Rev. Eur. Community Int. Environ. Law 15, 131–145.

Climate Strategies, 2019. Building blocks for a climate-neutral European industrial sector. Clim. Strateg. Rep.

Cosbey, A., Droege, S., Fischer, C., Munnings, C., 2019. Developing Guidance for Implementing Border Carbon Adjustments: Lessons, Cautions, and Research Needs from the Literature. Rev. Environ. Econ. Policy 13, 3–22. doi:10.1093/reep/rey020

Davis, S.J., Lewis, N.S., Shaner, M., Aggarwal, S., Arent, D., Azevedo, I.L., Benson, S.M., Bradley, T., Brouwer, J., Chiang, Y.-M., others, 2018. Net-zero emissions energy systems. Science 360.

de Bruyn, S.M., Vergeer, R., schep, E., Hoen, M., Kurteland, M., Cludius, J., Schumacher, K., Zell-Ziegler, C., Healy, S., 2015. Ex-post investigation of cost pass-through in the EU ETS: an analysis for six sectors. Publications Office, Luxembourg.

Demailly, D., Quirion, P., 2008. European Emission Trading Scheme and competitiveness: A case study on the iron and steel industry. Energy Econ. 30, 2009–2027. doi:10.1016/j.eneco.2007.01.020

DESTATIS, 2015. Einkommens- und Verbrauchsstichprobe. Aufwendungen privater Haushalte für den Privaten Konsum 2013.

Eurostat, 2020. PRODCOM Annual Data 2019.

Evans, S., Mehling, M., Ritz, R., Sammon, P., 2020. Border Carbon Adjustments and Industrial Competitiveness in a European Green Deal (EPRG Working Paper No. 2007).

Felbermayr, G., Peterson, S., 2020. Economic assessment of Carbon Leakage and Carbon Border Adjustment. Directorate General for External Policies of the EU.

Goulder, L.H., Parry, I.W., 2008. Instrument choice in environmental policy. Rev. Environ. Econ. Policy 2, 152–174.

Hardadi, G., Buchholz, A., Pauliuk, S., 2020. Implications of the distribution of German household environmental footprints across income groups for integrating environmental and social policy design. J. Ind. Ecol.

Horton, P.M., Allwood, J.M., 2017. Yield improvement opportunities for manufacturing automotive sheet metal components. J. Mater. Process. Technol. 249, 78–88.

IEA, 2018. Technology Roadmap: Low-Carbon Transition in the Cement Industry. International Energy Agency / Cement Sustainability Initiative.
IEA, 2017. Energy Technology Perspectives 2017. International Energy Agency.
Ismer, R., Neuhoff, K., Pirlot, A., 2020. Border Carbon Adjustments and Alternative Measures for the EU ETS: An Evaluation (DIW Discussion Paper No. 1855).
Martin, R., Muûls, M., De Preux, L.B., Wagner, U.J., 2014. Industry compensation under relocation risk: A firm-level analysis of the EU emissions trading scheme. Am. Econ. Rev. 104, 2482–2508.
Martin, R., Muûls, M., Wagner, U.J., 2016. The impact of the European Union Emissions Trading Scheme on regulated firms: what is the evidence after ten years? Rev. Environ. Econ. Policy 10, 129–148.
Material Economics, 2019. Industrial Transformation 2050 - Pathways to Net-Zero Emissions from EU Heavy Industry.
Naegele, H., Zaklan, A., 2019. Does the EU ETS cause carbon leakage in European manufacturing? J. Environ. Econ. Manag. 93, 125–147. doi:10.1016/j.jeem.2018.11.004
Neuhoff, K., Ritz, R., 2019. Carbon cost pass-through in industrial sectors. doi:10.17863/CAM.46544
Pauliuk, S., Neuhoff, K., Owen, A., Wood, R., 2016. Quantifying Impacts of Consumption Based Charge for Carbon Intensive Materials on Products (DIW Discussion Papers No. 1570).
Pollitt, H., Neuhoff, K., Lin, X., 2020. The impact of implementing a consumption charge on carbon-intensive materials in Europe. Clim. Policy 20, S74–S89.
Röller, L.-H., Steen, F., 2006. On the Workings of a Cartel: Evidence from the Norwegian Cement Industry. Am. Econ. Rev. 96, 321–338. doi:10.1257/000282806776157713
Sato, M., Neuhoff, K., Graichen, V., Schumacher, K., Matthes, F., 2015. Sectors under scrutiny: evaluation of indicators to assess the risk of carbon leakage in the UK and Germany. Environ. Resour. Econ. 60, 99–124.
Smale, R., Hartley, M., Hepburn, C., Ward, J., 2006. The impact of CO2 emissions trading on firm profits and market prices. Clim. Policy 19.
Stadler, K., Wood, R., Bulavskaya, T., Södersten, C.-J., Simas, M., Schmidt, S., Usubiaga, A., Acosta-Fernández, J., Kuenen, J., Bruckner, M., others, 2018. EXIOBASE 3: Developing a time series of detailed environmentally extended multi-regional input-output tables. J. Ind. Ecol. 22, 502–515.
Stiglitz, J.E., Stern, N., Duan, M., Edenhofer, O., Giraud, G., Heal, G.M., La Rovere, E.L., Morris, A., Moyer, E., Pangestu, M., others, 2017. Report of the high-level commission on carbon prices. World Bank, Washington, DC.
Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E., Weidema, B., 2016. The ecoinvent database version 3 (part I): overview and methodology. Int. J. Life Cycle Assess. 21, 1218–1230.
Wier, M., Birr-Pedersen, K., Jacobsen, H.K., Klok, J., 2005. Are CO2 taxes regressive? Evidence from the Danish experience. Ecol. Econ. 52, 239–251.
World Steel Association, 2020. World Steel in Figures.